Revealing the nature of the highly obscured galactic source IGR J16318-4848

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REVEALING THE NATURE OF THE HIGHLY OBSCURED GALACTIC SOURCE IGR J16318−4848

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ABSTRACT

The X-ray source IGR J16318−4848 was the first source discovered by INTEGRAL on 2003, January 29. The high energy spectrum exhibits such a high column density that the source is undetectable in X-rays below 2 keV. On 2003, February, 23–25 we triggered a Target of Opportunity (ToO) program using the EMMI and SOFI instruments on the New Technology Telescope of the European Southern Observatory (La Silla) to get optical and near-infrared (NIR) observations. We discovered the optical counterpart, and confirmed the already proposed candidate in the NIR. We report here photometric measurements in the R, I and J bands, upper flux limits in the Bb and V bands, lower flux limits in the H and K_s bands. We also got NIR spectroscopy between 0.95 and 2.52 μm, revealing a large amount of emission lines, including forbidden iron lines and P-Cygni profiles, and showing a strong similarity with CI Cam, another strongly absorbed source. Together with the Spectral Energy Distribution (SED), these data point to a high luminosity, high temperature source, with an intrinsic absorption greater than the interstellar absorption, but two orders of magnitude below the X-ray absorption. We propose the following picture to match the data: the source is a High Mass X-ray binary (HMXB) at a distance between 0.9 and 6.2 kpc, the optical/NIR counterpart corresponds to the mass donor, which is an early-type star, probably a sgB[e] star, surrounded by a dense and absorbing circumstellar material. This would make the second HMXB with a sgB[e] star as the mass donor after CI Cam. Such sources may represent a different evolutionary state of X-ray binaries previously undetected with the lower energy space telescopes; if it is so, a new class of strongly absorbed X-ray binaries is being unveiled by INTEGRAL.

Key words: stars: circumstellar matter, emission-line, Be–X-rays: binaries, IGR J16318−4848.

Based on observations collected at the European Southern Observatory, Chile (proposal ESO N° 70.D-0340).

1. INTRODUCTION

IGR J16318−4848 was the first new source discovered by the INTEGRAL IBIS/ISGRI imager (Ubertini et al. 2003; Lebrun et al. 2003). The source was detected on 2003 January 29 in the energy band 15–40 keV with a mean 20–50 keV flux of $6 \times 10^{11}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$, 0.5° south from the galactic equator (Courvoisier et al. 2003). The source was thereafter regularly observed for two months. No X-ray counterpart could be found in the ROSAT All Sky Survey (Voges et al. 1999). The source was observed by XMM-Newton on 2003 February 10, which detected a single X-ray source within the INTEGRAL error box using the EPIC PN and MOS cameras (Strüder et al. 2001; Turner et al. 2001), giving the most precise position to date: $\alpha = 16^{\mathrm{h}}31^{\mathrm{m}}48\overset{\mathrm{s}}{.}6$, $\delta = -48°49'00''$ with a $4''$ error box (Schartel et al. 2003). X-ray spectroscopy revealed a very high absorption column density: $N_{\mathrm{H}} > 10^{24}\,\mathrm{cm^{-2}}$ (Matt & Guainazzi 2003; Walter et al. 2003; Walter et al. 2004), which renders the source invisible below 2 keV. This amount of absorption is unusual in Galactic sources. This could explain the non detection by ROSAT, although the source was discovered at a similar flux level in archival ASCA observations in 1994 (Murakami et al. 2003) on both GIS and SIS instruments (between 0.4 and 10 keV). Relatively bright and highly absorbed sources like IGR J16318−4848 could have escaped detection in past X-ray surveys and could still contribute significantly to the Galactic hard X-ray background in the 10–200 keV band. Based on the broad high-energy spectral and variability characteristics, Walter et al. (2004) suggest that IGR J16318−4848 is an X-ray binary, the low temperature and presence of cutoff at low energy suggesting that the compact object is a neutron star.
The high column density prompted counterpart research in near-infrared (NIR): within the EPIC error box, a possible counterpart was proposed by Foschini et al. (2003) using the Two Micron All Sky Survey (2MASS) with the following magnitudes: $J = 10.2$, $H = 8.6$, $K_s = 7.6$ with an uncertainty of ± 0.3 mag (Walter et al. 2003). On the other hand, no radio

emission at the position of the source could be detected. In the course of a Target of Opportunity (ToO) program at the European Southern Observatory (ESO) dedicated to look for counterparts of high energy sources newly discovered by satellites including INTEGRAL (PI S. Chaty), we carried out on 2003, February, 23-25 photometric observations in the optical and NIR, and spectroscopic observations in the NIR with EMMI and SOFI instruments on ESO/NTT. The goals were to search for likely counterparts within the EPIC error box, to get informations about the environment and the nature of the source, especially about the mass donor.
In the following, we describe briefly our observations, report our main results on astrometry, photometry, spectral energy distribution, absorption and temperature estimates of the most likely candidate. We also summarize our results on spectral lines, distance to the source, and conclude on its nature and the nature of its components. The reader should consult Filliatre and Chaty (2004) for more details (and Chaty and Filliatre 2004 for a condensed version).

2. OBSERVATIONS AND RESULTS

The source IGR J16318−4848 was the first source discovered by INTEGRAL. In the course of a ToO program using the NTT telescope, we performed photometric and spectroscopic observations less than one month after its discovery in the optical and NIR domains. We list here the main results:

- We discovered the optical counterpart and confirmed an already proposed NIR candidate (see Walter et al., 2003), by performing an independent astrometry for this candidate, giving the following position for the candidate: $\alpha = 16^{\mathrm{h}}31^{\mathrm{m}}48\overset{\mathrm{s}}{.}3$ $\delta = -48°49'01''$. The optical/NIR images and spectra are shown in Figures 1 and 2.
- We obtained photometric measurements for the R, I and J bands, and got flux upper limits for B and V, flux lower limits for H and K_s: $Bb > 25.4 \pm 1$, $V > 21.1 \pm 0.1$, $R = 17.72 \pm 0.12$, $I = 16.05 \pm 0.54$ $J = 10.33 \pm 0.14$, $H < 10.35 \pm 0.15$ $K_s < 9.13 \pm 0.10$.
- We derived the absorption towards the source along the line of sight: Av$\sim$ 17.4 magnitudes, greater than interstellar (11.8 mag, see Fig. 3) but 2 orders of magnitude lower than in X-rays.
- With the continua of our GBF (Grism Blue Filter) and GRF (Grism Red Filter) spectra, our photometric measurements and with X-ray, radio and archival data, we constructed a SED, shown in Fig. 4, covering 10 decades in wavelength.
- From this SED, we derive that the companion star must be a high luminosity, high temperature star: above 10 000 K.
- No radio emission associated with a low/hard X-ray state suggests that the compact object is a neutron star.
- The distance of the source is constrained between 0.9 and 6.2 kpc.
- The $0.95 - 2.52$ μm NIR spectra, shown in Figures 5, 6 and 7, are highly unusual, very rich in emission lines (we identified 72 emission lines), including forbidden iron lines and P-Cygni profiles. The lines in the spectrum show no cosmological redshift, confirming that the object is galactic.
- 80 % of these lines have been detected in CI Cam, suggesting a similar nature.
- These spectra favor the existence of a highly complex, stratified and dense circumstellar environment, with stellar wind or enveloppe.
- The type of the companion star is consistent with the position on the colour-magnitude HR diagram, computed for various absorption values and distances (see figure 8).
- Study of the spectral lines, of the SED and of the CMD suggest a sgB[e] star so the system would be a HMXB, probably hosting a neutron star, like CI Cam. This HMXB hosting a sgB[e] star is the most likely hypothesis; it would then be the second case after CI Cam.

Complementary observations are needed in order to confirm our results, among them we propose:

- high resolution NIR spectroscopy, if possible extended to optical, in order to:
  - extend the SED in the optical to directly see a NIR excess;
  - check if the similarity with CI Cam observed in the NIR is still valid in the optical; however this will be difficult because of the absorption;
  - improve our results concerning P-Cygni profiles, and line broadening;
- long term follow-up spectroscopy and photometry, in order to:
  - seek for line variability;
  - seek for a periodic behaviour to infer the orbital elements.
- simultaneous multi-wavelength observations, in order to better understand the nature and geometry of the system

This source shows many unusual features, the first being its strong intrinsic absorption. Interestingly, among the ten sources that INTEGRAL has discovered in this region, this feature is common (at least

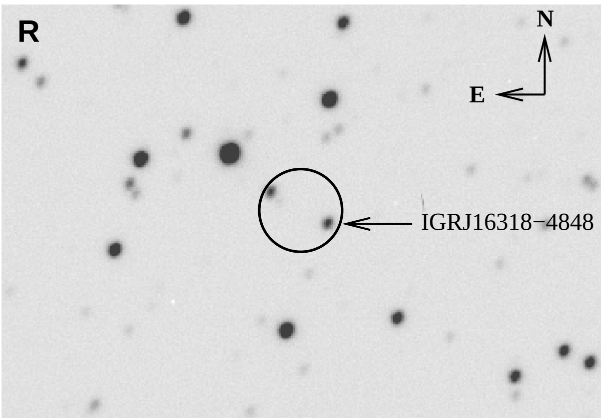

Figure 1. EMMI R band image of the field of view of IGR J16318−4848. We reported the XMM error box of 4″. North is up, east is left. The scale is given by the error box. The most likely candidate is at the south-west border of the circle as indicated by the arrow.

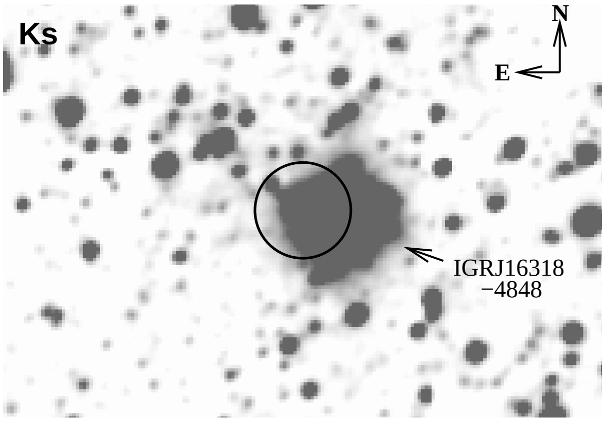

Figure 2. Ks band image of the same field.

in the X-rays), to the three sources discussed by Revnivtsev 2003: IGR J16318−4848, IGR J16320-4751 and IGR J16358-4726, although the N_{H} column density is lower by an order of magnitude in the two latter systems (Rodriguez et al. 2003; Patel et al. 2004). However, a clear identification for the optical/NIR counterpart has been done only for IGR J16318−4848. Moreover, the type of the mass donor, as inferred from our study, has been considered up to now as very rare. There is therefore the possibility that INTEGRAL, with the discovery of IGR J16318−4848, has unveiled a new class of obscured high energy binaries (see also Walter et al. 2004). This class will deserve much attention in the future, because they might help us to understand the evolution of high-energy binary systems.

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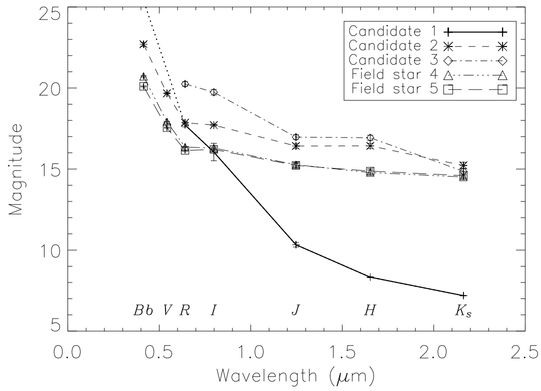

Figure 3. Magnitudes of IGR J16318-4848 (called here candidate 1) and field stars

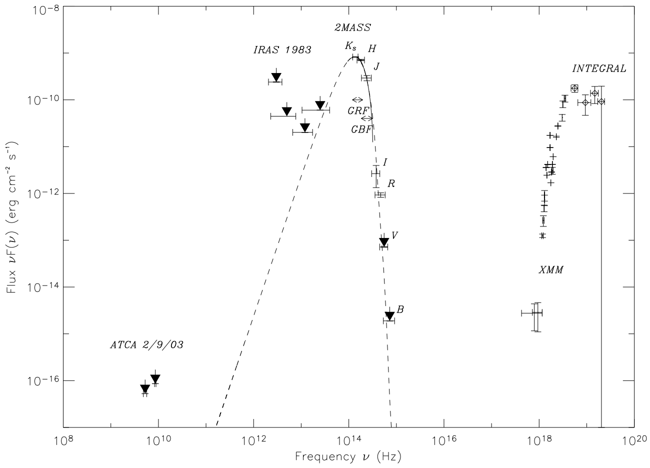

Figure 4. Observed SED of IGR J16318-4848 in $(\nu,\ \nu F(\nu))$ units, including the results of our photometry, our rescaled continuum GBF and GRF spectra, and literature data. The B and V data are upper limits only. The dashed curve corresponds to an absorbed black body, representing well the data. The results of INTEGRAL, XMM, IRAS and ATCA are also shown.

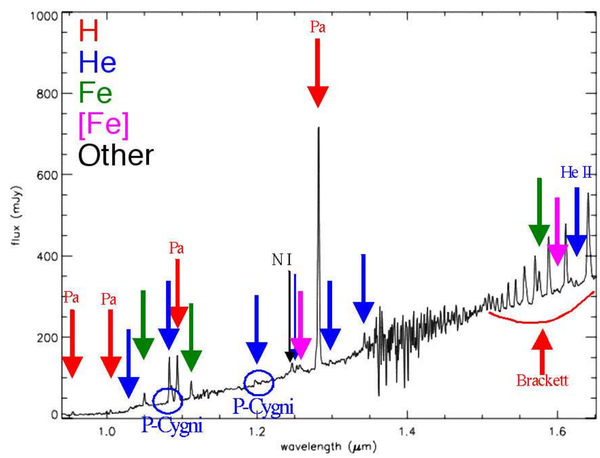

Figure 5. NIR GBF spectrum (0.95-1.65 μm)

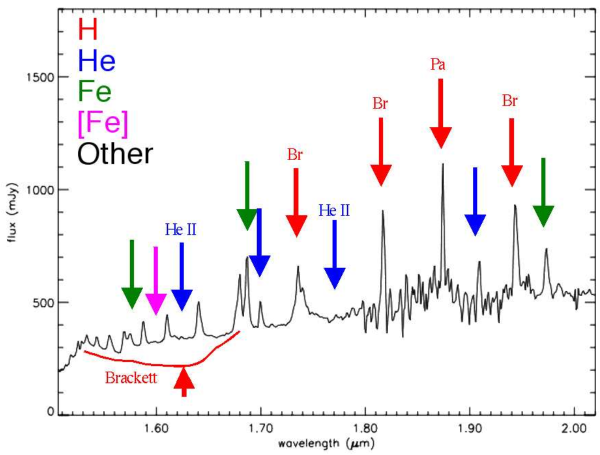

Figure 6. NIR GRF spectrum (1.5-2.05 μm)

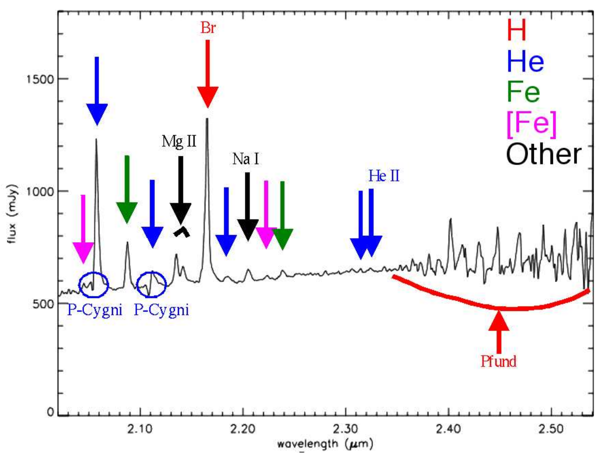

Figure 7. NIR spectrum (2.0-2.55 μm)

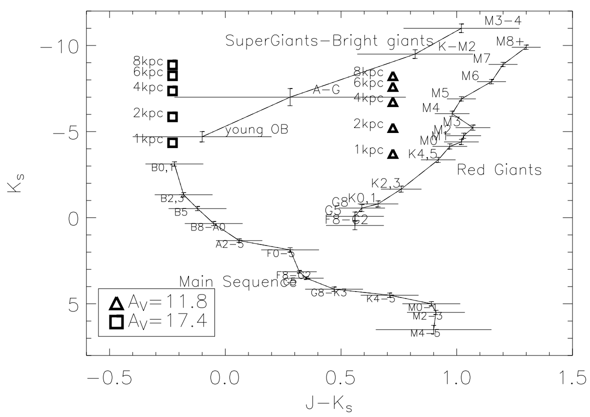

Figure 8. Position on the color-color HR diagram computed from template stars of Ruelas-Mayorga 1991, for distance from 1 to 8 kpc, and for two absorption values: $A_V = 17.4$ and $A_V = 11.8$.

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